



### Variable-Structure Control of a Model Glider Airplane

**The conventional spin-recovery technique for fuselage-heavy aircraft is implemented by a modern control system.**

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A variable-structure control system designed to enable a fuselage-heavy airplane to recover from spin has been demonstrated in a hand-launched, instrumented model glider airplane (see figure). It has long been known that the most effective spin recovery technique for fuselage-heavy aircraft involves the use of ailerons to roll the airplane into the spin. This technique might be considered counter-intuitive because the pro-spin aileron deflection tends to ini-



This **Model Glider Airplane**, instrumented with sensors and control and data-acquisition systems, was used to demonstrate the use of variable-structure control for spin recovery.

tially increase the roll-rate component of the angular momentum of the airplane. However, it restores some controllability, enabling the pilot to perform subsequent maneuvers to pull out of the spin. The design of the present model-airplane control system was inspired in part by recognition that the aforementioned (and conventional) spin-recovery technique mimics a variable-structure control law.

Variable-structure control is a high-speed switching feedback control technique that has been developed for control of nonlinear dynamic systems. A variable-structure control law typically has two phases of operation, denoted the reaching-mode and sliding-mode phases. In the reaching-mode phase, a nonlinear relay control strategy is followed to drive the trajectory of the system to a pre-defined switching surface within the motion state space. The sliding-mode phase involves motion along the switching surface as the system moves toward an equilibrium or critical point.

A theoretical analysis has led to the conclusion that the conventional spin-recovery technique can be interpreted as a variable-structure control law with a switching surface defined at zero yaw rate. Application of Lyapunov stability

methods in the theoretical analysis showed that deflecting the ailerons in the direction of the spin helps to insure that this switching surface is stable. It was shown that during the reaching-mode phase, a simple relay control law would drive the airplane to a critical point that would be characterized by almost pure rolling motion. The sliding-mode-phase control law would then eliminate the rolling motion, leading to a complete recovery.

For the demonstration of variable-structure control for spin recovery, the model airplane was equipped with attitude sensors and a microcontroller that drove servomechanisms for controlling the deflections of the ailerons, rudder, and elevator. A variable-structure control law incorporating a nonlinear model of the aerodynamic characteristics of the airplane was implemented in firmware. Flight tests have verified the stability of the reaching-mode phase.

*This work was done by Martin R. Waszak of Langley Research Center and Mark R. Anderson of Paper Pilot Research, Inc. Further information is contained in a TSP (see page 1).  
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### Axial Halbach Magnetic Bearings

**Complex active control systems are not needed.**

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Axial Halbach magnetic bearings have been investigated as part of an effort to develop increasingly reliable noncontact bearings for future high-speed rotary machines that may be used in such applications as aircraft, industrial, and land-vehicle power systems and in some medical and scientific instrumentation systems. Axial Halbach magnetic bearings are passive in the sense that unlike

most other magnetic bearings that have been developed in recent years, they effect stable magnetic levitation without need for complex active control.

In simplest terms, the basic principle of levitation in an axial Halbach magnetic bearing is that of the repulsive electromagnetic force between (1) a moving permanent magnet and (2) an electric current induced in a stationary

electrical conductor by the motion of the magnetic field. An axial Halbach bearing includes multiple permanent magnets arranged in a Halbach array ("Halbach array" is defined below) in a rotor and multiple conductors in the form of wire coils in a stator, all arranged so the rotary motion produces an axial repulsion that is sufficient to levitate the rotor.

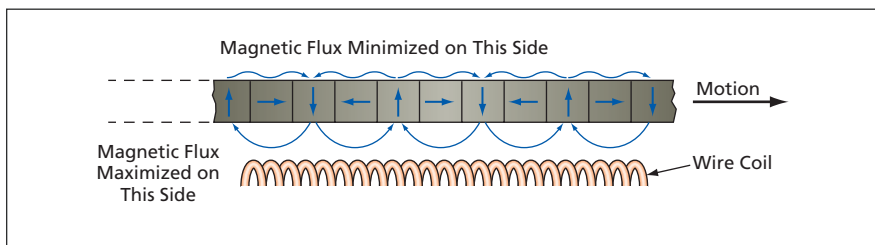


Figure 1. A **Basic Halbach Array** consists of permanent magnets oriented in a sequence of quarter turns chosen to concentrate the magnetic field on one side. The motion of the array along a wire coil gives rise to an electromagnetic repulsion that can be exploited for levitation.

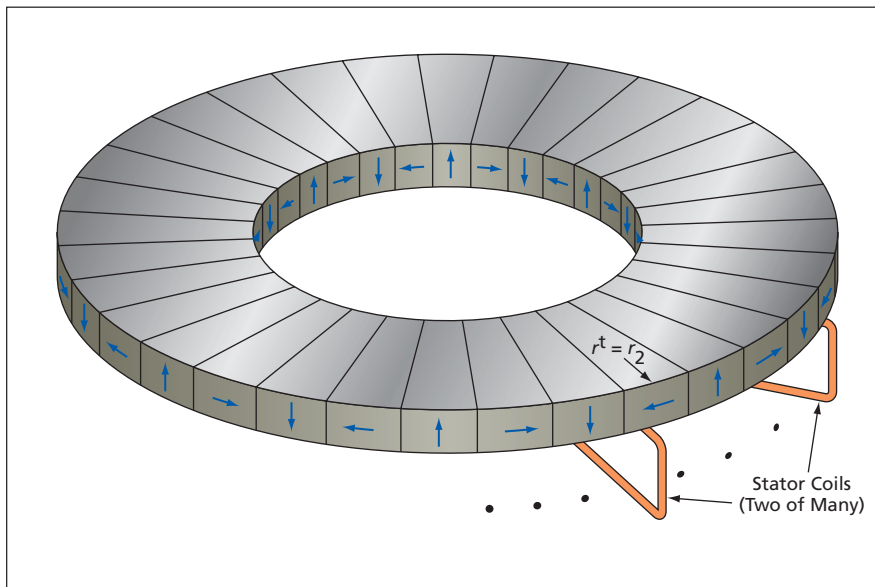


Figure 2. An **Axial Halbach Magnetic Bearing** includes a symmetrical disk version of the Halbach array of Figure 1 plus multiple stator coils in a symmetrical array below the magnet disk. For simplicity, only two of the stator coils are shown.

A basic Halbach array (see Figure 1) consists of a row of permanent magnets, each oriented so that its magnetic field is at a right angle to that of the adjacent magnet, and the right-angle turns are sequenced so as to maximize the magnitude of the magnetic flux density on one side of the row while minimizing it on

the opposite side. The advantage of this configuration is that it makes it possible to approach the theoretical maximum force per unit area that could be exerted by a given amount of permanent-magnet material. The configuration is named after physicist Klaus Halbach, who conceived it for use in particle accelerators.

Halbach arrays have also been studied for use in magnetic-levitation (“maglev”) railroad trains.

In an axial Halbach magnetic bearing, the basic Halbach arrangement is modified into a symmetrical arrangement of sector-shaped permanent magnets in a disk on the rotor (see Figure 2). The magnets are oriented to concentrate the magnetic field on one of the axial faces of the disk — the lower face in Figure 2. The stator coils are mounted in a symmetrical arrangement below the disk.

At a given radial and axial coordinate relative to the disk, the magnetic flux along any given direction varies approximately sinusoidally with the azimuthal angular coordinate. When the disk rotates, the temporal variation of the magnetic field intercepted by the stator coils induces electric currents, thereby generating a repulsive electromagnetic force. The circuits of the stator coils may be terminated with external inductors, the values of which are chosen to modify the phase shifts of voltage and currents so as to maximize the axial repulsion. At and above a critical speed that depends on the specific design, the repulsive force is sufficient to levitate the rotor. During startup, shutdown, and other events in which the rate of rotation falls below the critical speed, the rotor comes to rest on an auxiliary mechanical bearing.

*This work was done by Dennis J. Eichenberg, Christopher A. Gallo, and William K. Thompson of Glenn Research Center. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18066-1.*

## **Compact, Non-Pneumatic Rock-Powder Samplers**

**Tool bits for ultrasonic/sonic drill/corers are modified to trap small particles.**

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Tool bits that automatically collect powdered rock, permafrost, or other hard material generated in repeated hammering action have been invented. These tool bits are intended primarily for use as parts of ultrasonic/sonic drill corers (USDCs) and related apparatuses, which have been reported in numerous prior *NASA Tech Briefs* articles. A USDC is based on the concept of a

miniature, lightweight, low-power, piezoelectrically driven hammering mechanism that is excited with a combination of ultrasonic and sonic vibrations that enable its tool bit to bore into rock or other hard, brittle material with very little applied force. There are numerous potential applications for such apparatuses in geological exploration on Earth and on remote planets. Typi-

cally, in such an exploration, the purpose served by a USDC is to cut samples of fragmented rock from one or more depth(s).

The present invention pertains to the special case in which it is desired to collect samples in powder form for analysis by x-ray diffraction and possibly other techniques. In one prior approach, rock fragments generated by a USDC or